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IMPROVEMENT OF POWER QUALITY IN P-V BASED DISTRIBUTION GRID WITH D-STATCOM

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ABSTRACT

Whenever there is a penetration of photovoltaic cell power to the low voltage distributed grid, there occur the problem of mismatch in voltage and frequency in the network, perhaps caused by non linear loads. In this paper one of the FACTS controller devices D-STATCOM is used to improve the voltage regulation thereby the power system stability. It uses a back propagation (BP) control algorithm for its functions such as harmonic elimination, load balancing and reactive power compensation for power factor correction, and zero voltage regulation under nonlinear loads. The above proposed model has been analyzed under various operating conditions and the performance of the model is evaluated using MATLAB SIMULINK software. The Simulink results are evaluated and the effectiveness of the given system is established.

KEYWORDS: D-STATCOM, Back Propagation (BP) Control Algorithm, Harmonics, Load Balancing, Power Quality, Weights

INTRODUCTION

With the advent of power semiconductor switching devices, like thyristors, GTO's, IGBT's and many more devices, control of electric power has become a reality. Such power electronic controllers are widely used to feed electric power to electrical loads. The power electronic devices due to their inherent non-linearity draw harmonic and reactive power from the supply. In three phase systems, they could also cause unbalance and draw excessive neutral currents. In addition to this, the power system is subjected to various transients like voltage sags, swells, flickers etc. These transients would affect the voltage at distribution levels. Excessive reactive power of loads would increase the generating capacity of generating stations and increase the transmission losses in lines. Power Quality (PQ) has become an important issue since many loads at various distribution ends like adjustable speed drives, process industries, printers; domestic utilities, computers, microprocessor based equipments etc. have become intolerant to voltage fluctuations, harmonic content and interruptions. Power Quality (PQ) mainly deals with issues like maintaining a fixed voltage at the Point of Common Coupling (PCC) for various distribution voltage levels irrespective of voltage fluctuations, maintaining near unity power factor power drawn from the supply, blocking of voltage and current unbalance from passing upwards from various distribution levels, reduction of voltage and current harmonics in the system and suppression of excessive supply neutral current.

Nowadays equipments using power semiconductor devices, generally known as active power filters (APF's), Active Power Line Conditioners (APLC's) etc. are used for the power quality issues due to their dynamic and adjustable solutions along with FACTS devices and Custom Power products like DSTATCOM. The performance of any custom

power device depends very much upon the control algorithm used for the reference current estimation and gating pulse generation scheme. Some of the classical control algorithms are the Fryze power theory, Budeanu theory, p-q theory and SRF theory [2]–[4],Lyapunov-function-based control and nonlinear control technique, etc.

Many nonmodel and training-based alternative control algorithms are also used with the application of soft computing technique such as neural network, fuzzy logic and adaptive neuro-fuzzy, etc. [5]. Adaptive learning, self organization, real-time operation, and fault tolerance through redundant information are major advantages of these algorithms. A neural network-based control algorithm such as the Hopfield-type neural network is also used for the estimation of the amplitude and phase angles of the fundamental component both with highly distorted voltage by the assumption of known power frequency [6]. Feed forward back propagation (BP) artificial neural network (ANN) consists of various layers such as the input layer, hidden layer, and output layer. It is based on feed forward BP with a high ability to deal with complex nonlinear problems. The BP control algorithm is also used to design the pattern classification model based on decision support system. Some applications of this algorithm are as to the identification of user faces, industrial processes, data analysis, mapping data, control of power quality improvement devices, etc.

In this paper, a BP algorithm is implemented in a three phase shunt connected custom power device known as DSTATCOM for the extraction of the weighted value of load active power and reactive power current components in nonlinear loads. The proposed control algorithm is used for harmonic suppression and load balancing in PFC and zero voltage regulation (ZVR) modes with dc voltage regulation of DSTATCOM. In this BP algorithm, the training of weights has three stages. It includes the feedforward of the input signal training, calculation and BP of the error signals, and upgrading of training weights. It may have one or more than one layer. Continuity, differentiability, and nondecreasing monotony are the main characteristics of this algorithm. It is based on a mathematical formula and does not need special features of function in the learning process. It also has smooth variation on weight correction due to batch updating features on weights. In the training process, it is slow due to more number of learning steps, but after the training of weights, this algorithm produces very fast trained output response. In this application, the proposed control algorithm on a DSTATCOM is implemented for the compensation of nonlinear loads.

PHOTOVOLTAIC SYSTEM

Photovoltaic (PV) is a method of generating electrical power by converting solar radiation into direct current electricity using semiconductors that exhibit the photovoltaic effect. Photovoltaic power generation employs solar panels comprising a number of cells containing a photovoltaic material. Materials presently used for photovoltaic include mono crystalline silicon, polycrystalline silicon, amorphous silicon, cadmium telluride, and copper indium selenide/sulfide.[1] Due to the growing demand for renewable energy sources, the manufacturing of solar cells and photovoltaic arrays has advanced considerably in recent years.

The photovoltaic effect is the generation of a voltage (or a corresponding electric current) in a material upon exposure to light. Though the photovoltaic effect is directly related to the photoelectric effect, the two processes are different and should be distinguished. In the photoelectric effect, electrons are ejected from a material's surface upon exposure to radiation of sufficient energy. The photovoltaic effect is different in that the generated electrons are transferred between different bands (i.e. from the valence to conduction bands) within the material, resulting in the buildup of a voltage between two electrodes. In most photovoltaic applications the radiation is sunlight and for this reason the devices are known as solar cells. In the case of a p-n junction solar cell, illumination of the material results in the generation of an

electric current as excited electrons and the remaining holes are swept in different directions by the built-in electric field of the depletion region. The photovoltaic effect was first observed by Alexander-Edmond Becquerel in 1839.

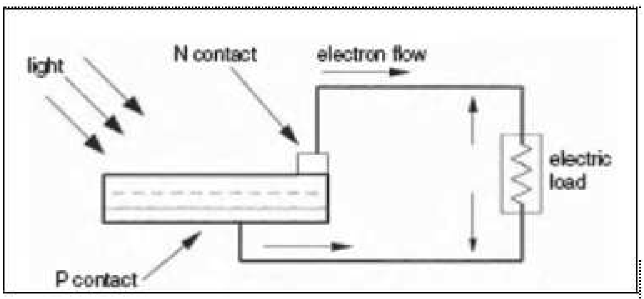


Figure 1: PV Effect Converts the Photon Energy into Voltage across the PN Junction

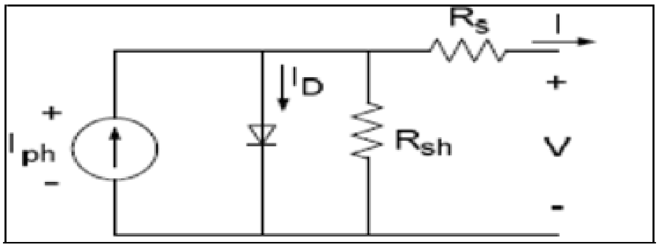


Figure 2: PV Cell Equivalent Circuit

The complex physics of the PV cell can be represented by the equivalent electrical circuit. The circuit parameters are as follows. The current Iat the output terminals is equal to the light-generated current I_L, less the diode current I_d and the shunt-leakage current I_{sh}. The series resistance R_s represents the internal resistance to the current flow, and depends on the pn junction depth, impurities, and contact resistance. The shunt resistance R_{sh} is inversely related to the leakage current to ground. In an ideal PV cell, R_s= 0Ω (no series loss), and R_{sh} = Ω(no leakage to ground). In a typical high-quality 1 in.2 silicon cell, Rs varies from 0.05 to 0.10 ΩR_{sh} from 200 to 300Ω. The PV conversion efficiency is sensitive to small variations in Rs, but is insensitive to variations in R_{sh}. A small increase in Rs can decrease the PV output significantly. In the equivalent circuit, the current delivered to the external load equals the current I_L generated by the illumination, less the diode current Id and the shunt leakage current I_{sh}. The open-circuit voltage Voc of the cell is obtained when the load current is zero, i.e., when I = 0, and is given by the following:

$$V_{OC} = V + IR_{Sh} \tag{1}$$

The shunt resistance (R_{sh}) is very large and the series resistance (Rs) is very small. Therefore, it is common to neglect these resistances in order to simplify the solar cell model. The resultant ideal voltage-current characteristic of a photovoltaic cell is given by the relation below and illustrated by the figure above.

$$I=I_{ph}-I_D \tag{2}$$

$$I=I_{ph}-I_0\left[\exp\left(\frac{q(V+R_sI)}{Ak_BT}\right)-1\right]-\frac{V+R_sI}{R_{sh}} \tag{3}$$

Where,

I_{ph} = photocurrent,

I_D = diode current,

I_0 = saturation current,

A = ideality factor,

q = electronic charge $1.6x10^{-9}$,

kB = Boltzmann’s gas constant ($1.38x10^{-23}$),

T = cell temperature,

R_s= series resistance,

R_{sh} = shunt resistance,

I = cell current,

V = cell voltage

The power output of a solar cell is given by

$$P_{PV} = V_{PV} * I_{PV} \quad (4)$$

Where

I_{PV} = Output current of solar cell (A).

V_{PV} = Solar cell operating voltage (V).

P_{PV} =Output power of solar cell (W).

It can be seen from the characteristics, that there is a unique point on the characteristics at which the photovoltaic power is maximum. This point is termed as the maximum power point (MPP). The power corresponding to this point is termed as power at maximum power point (P_{mpp}) and the voltage as voltage at maximum power point (V_{mpp}). Due to high cost of solar cells, it must be ensured that the photovoltaic array operates at all time to provide maximum power output. Hence a maximum power point tracker must be used to track the maximum power of the system. This is commonly known as maximum power point tracking (MPPT). Now if the irradiance level of the photovoltaic system is changed from the standard 1000 W/m^2 to say 600 W/m^2 or 400 W/m^2 then the P-V characteristic will change as shown in the figure below.

Need for Power Quality Improvement

Equipment has become less tolerant of voltage quality disturbances, production processes have become less tolerant of incorrect of incorrect operation of equipment, and companies have become less tolerant of production stoppages. Equipment produces more current disturbances than it used to do. Both low and high power equipment is more and more powered by simple power electronic converters which produce a broad spectrum of distortion. There are indications that the harmonic distortion in the power system is rising, but no conclusive results are obtained due to the lack of large scale surveys. The deregulation of the electricity industry has led to an increased need for quality indicators. Customers are demanding, and getting, more information on the voltage quality they can expect. Also energy efficient equipment is an important source of power quality disturbance. Adjustable speed drives and energy saving lamps are both important sources of waveform distortion and are also sensitive to certain type of power quality disturbances. When these power Quality problems become a barrier for the large scale introduction of environmentally friendly sources

and users' equipment, power quality becomes an environmental issue with much wider consequences than the currently merely economic issues.

DSTATCOM

Modern power systems are complex networks, where hundreds of generating stations and thousands of load centers are interconnected through long power transmission and distribution networks. Even though the power generation in most countries is fairly reliable, the quality of power is not so reliable. Power distribution system should provide their customers with an uninterrupted flow of energy at smooth sinusoidal voltage at the contracted magnitude level and frequency. Power system especially distribution systems have numerous non linear loads, which significantly affect the quality of power supplies. This ends up producing many power quality problems. Apart from non linear loads events like capacitor switching, motor starting and unusual faults could also inflict power quality problems. Power quality problem is defined as any manifested problem in voltage /current or leading to frequency deviations that result in failure or mis-operation of customer equipment. Voltage sags and swells are among the many power quality problems the industrial process has to face. Voltage sags are most severe. The DSTATCOM is a power quality device, which can protect these industries against the sags and swells. Usually sags and swells are related to remote faults. A DSTATCOM compensates for these voltage disturbances provided that supply grid does not get disconnected entirely through breaker trips. It can exchange both active and reactive power with the distribution system.

Principle and Operation of DSTATCOM

A D-STATCOM (Distribution Static Compensator), which is schematically depicted in Figure 3, consists of a two-level Voltage Source Converter (VSC), a dc energy storage device, a coupling transformer connected in shunt to the distribution network through a coupling transformer. The VSC converts the dc voltage across the storage device into a set of three-phase ac output voltages. These voltages are in phase and coupled with the ac system through the reactance of the coupling transformer. Suitable adjustment of the phase and magnitude of the D-STATCOM output voltages allows effective control of active and reactive power exchanges between the DSTATCOM and the ac system. Such configuration allows the device to absorb or generate controllable active and reactive power.

The VSC connected in shunt with the ac system provides a multifunctional topology which can be used for up to three quite distinct purposes:

- Voltage regulation and compensation of reactive power;
- Correction of power factor; and
- Elimination of current harmonics.

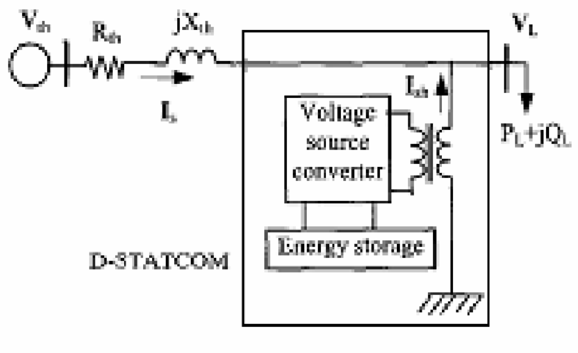


Figure 3: Schematic Diagram of a DSTATCOM

Figure 3 the shunt injected current Ish corrects the voltage sag by adjusting the voltage drop across the system impedance Zth. The value of Ish can be controlled by adjusting the output voltage of the converter. The shunt injected current Ish can be written as,

$$I_{sh}= I_L - I_S = I_L - (V_{th} - V_L)/Z_{th} \tag{5}$$

$$I_{sh}\angle\eta = I_L\angle-\theta - \frac{V_{th}}{Z_{th}}\angle(\delta-\beta) + \frac{V_L}{Z_{th}}\angle-\beta \tag{6}$$

The complex power injection of the D-STATCOM can be expressed as,

$$S_{sh} = V_L.I_{sh}^{*} \tag{7}$$

It may be mentioned that the effectiveness of the D-STATCOM in correcting voltage sag depends on the value of Zth or fault level of the load bus. When the shunt injected current Ish is kept in quadrature with VL, the desired voltage correction can be achieved without injecting any active power into the system. On the other hand, when the value of Ish is minimized, the same voltage correction can be achieved with minimum apparent power injection into the system

Voltage Source Converter

A voltage-source converter is a power electronic device, which can generate a sinusoidal voltage with any required magnitude, frequency and phase angle. Voltage source converters are widely used in adjustable-speed drives, but can also be used to mitigate voltage dips. The VSC is used to either completely replace the voltage or to inject the ‘missing voltage’. The ‘missing voltage’ is the difference between the nominal voltage and the actual. The converter is normally based on some kind of energy storage, which will supply the converter with a DC voltage. The solid-state electronics in the converter is then switched to get the desired output voltage. Normally the VSC is not only used for voltage dip mitigation, but also for other power quality issues, e.g. flicker and harmonics.

Control Scheme for the DSTACOM

In the BP training algorithm, the phase PCC voltages (v_{sa}, v_{sb}, and v_{sc}), source currents (i_{sa}, i_{sb}, and i_{sc}), load currents (i_{La}, i_{Lb}, and i_{Lc}) and dc bus voltage (v_{dc}) are required for the extraction of reference source currents (i^*_{sa}, i^*_{sb}, and i^*_{sc}). There are two primary modes for the operation of this algorithm: The first one is a feedforward, and the second is the BP of error or supervised learning. The detail application of this algorithm for the estimation of various control parameters is given as follows.A BP training algorithm is used to estimate the three phase weighted value of load

active power current components (w_{ap},w_{bp},andw_{cp}) and reactive power current components (w_{aq},w_{bq},andw_{cq}) from polluted load currents using the feedforward and supervised principle. It is the relation of the phase voltage and the amplitude of the PCC voltage (v_t). The below figure shows the test system used to carry out the various DSTATCOM simulations.

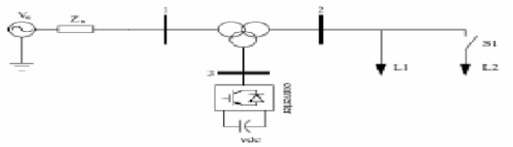


Figure 4: single Line Diagram of the Test System for DSTATCOM

Where Vs = 3-ph Voltage generator,

Zs = Source Impedance,

Vdc = DC voltage Source

1,2 and 3 are known as feeders or buses to which we connect various electric equipments

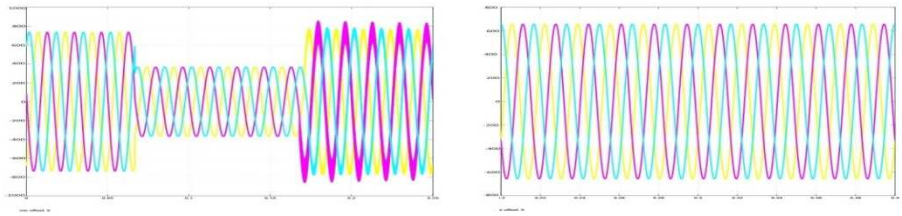
L1, L2 are the loads connected to the system

S1 is the switch

Switch S1 is used to attain various situations in the power system, i.e. sags, swells. In the actual practice we are using CB (Circuit breaker instead of switch), by varying the intial positions of the CB. We are performing the tests by using DSTATCOM.

RESULTS

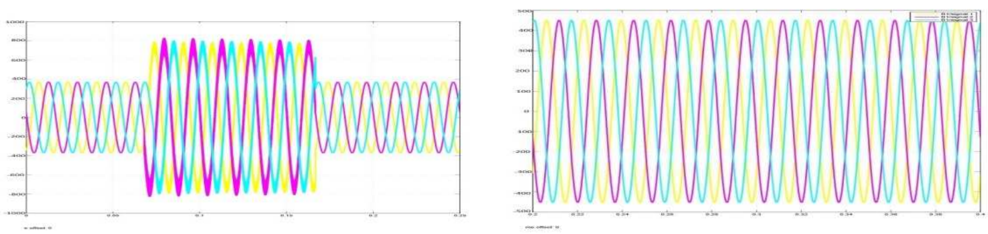
Simulation Results for Voltage Sag



Without DSTATCOM **With DSTATCOM**

Figure 5

Simulation Results for Voltage Swell



Without DSTATCOM **With DSTATCOM**

Figure 6

CONCLUSIONS

This paper has presented the power quality problems such as voltage dips, swells and interruptions, consequences, and mitigation techniques of custom power electronic device D-STATCOM. The design and applications of D-STATCOM for voltage sags, interruptions and swells, and comprehensive results are presented. The proposed BPT control algorithm has been used for the extraction of reference source currents to generate the switching pulses for IGBTs of the VSC of DSTATCOM. Various functions of DSTATCOM such as harmonic elimination and load balancing have been demonstrated in PFC and ZVR modes with dc voltage regulation of DSTATCOM. From the simulation and implementation results, it is concluded that DSTATCOM and its control algorithm have been found suitable for the compensation of nonlinear loads. Its performance has been found satisfactory for this application because the extracted reference source currents exactly traced the sensed source currents during the steady state as well as dynamic conditions. The dc bus voltage of the DSTATCOM has also been regulated to the rated value without any overshoot or undershoot during load variation. Large training time in the application of the complex system and the selection of the number of hidden layers in the system are the disadvantages of this algorithm.

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